STUDY ON DESIGN AND PERFORMANCE COMPARISON OF RC BUILDINGS DESIGNED FOR VARIOUS INDIAN SEISMIC ZONES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

In

Civil Engineering

By

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Department of Civil Engineering
National Institute of Technology
Rourkela

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CERTIFICATE

This is to certify that the thesis entitled **"STUDY ON DESIGN AND PERFORMANCE COMPARISON OF RC BUILDINGS DESIGNED FOR VARIOUS INDIAN SEISMIC ZONES"** submitted by **Mausam Shrestha (111CE0052),** in the partial fulfillment of the requirement for the degree of **Bachelor of Technology** in **Civil Engineering**, National Institute of Technology, Rourkela, is an authentic work carried out by him under my supervision.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any other university/institute for the award of any degree or diploma.

Date:

(Prof. Robin Davis P.)

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Reinforced concrete (RC) buildings are routinely designed and detailed to have somewhat higher strengths than those required for actual service load conditions. Generally, the members are provided with larger sizes and greater material strengths than the minimum design requirements a stipulated in the building design codes. The present design procedures for seismic design also results in greater strengths. Moreover, the redundancy in the structure on account of in redistribution of stresses will also lead to increased overall strength. This study deals with the comparison of percentage longitudinal steel, reinforcement detailing and design base shear of three RC framed buildings with varying storey heights in different Indian seismic zones. Moreover, it also comprises of performance based analysis of the buildings taken under consideration and designed as per Indian codal provisions in terms of their over-strength factor using computer-based push-over analysis.

1

INTRODUCTION

CHAPTER-1

INTRODUCTION

1.1 SEISMIC DESIGN PHILOSOPHY

A severe earthquake is one of the most destructive phenomena of nature. It is quite impossible to precisely predict and prevent an earthquake , but the damage to a structure can be reduced by its proper design. Hence it is prudent to do the seismic analysis and design to prevent structures against any catastrophe. The severity of the damage depends on the combination of several factors such as- earthquake magnitude, proximity to epicenter, and the local geological conditions, which affect the seismic wave propagation. The lateral forces due to earthquake cause the maximum problem for structures.

Earthquake resistant design is thereby primarily concerned with limiting the seismic risk associated with man-made structures to socio-economically acceptable levels. It aims to foresee the potential consequences of an earthquake on civil infrastructure and to ensure the design & construction of buildings complies with design codes in order to maintain a reasonable level of performance with some accepted level of damage during an earthquake exposure .The ductility of a structure acts like a shock absorber and helps in dissipating a certain amount of seismic energy.

1.2 PUSHOVER ANALYSIS

It is a non-linear structural analysis technique in which an incremental lateral load is applied to the structure under consideration. The sequential progress of crack formation, plastification, inter-storey drift and yielding can be aptly monitored through this method. It is an iterative process and continues till the design fulfills some pre-defined criterion such as target roof displacement. Roof displacement is often taken as the failure criteria because of the ease associated with its estimation. This has become a widely used tool for the purpose of seismic analysis and design of new as well as existing buildings .

1.3 BACKGROUND AND MOTIVATION OF THE PRESENT STUDY

The present work in its utmost sense, tries to delineate that what will be the changes in the structural design of buildings with variation in the seismic zones. It helps in giving a generalized sense of design and detailing differences that will be taking place with the increment in probable severity of ground motions. Thereby, aiding in developing a general perception about the design of regular RC buildings particularly in India. Jain *et al*. (2008), has done the detailing comparison for some selected members of a six-storey building, considering it once as an OMRF and once as an SMRF. The similar idea has been used in this work as well, the buildings in zone II have been considered OMRF and detailed as per IS 456, and those in higher seismic zones have been considered as SMRF and detailed as per IS 13920. This study moreover, attempts to do a comparison of the base shear, percentage reinforcement in beams and columns for all the various zones.so as to give further insights into the design aspects. Kumar *et al.* (2013) has carried out such comparison for all components of a G+4 building .This work in addition to all such comparison, includes pushover analysis of the designed buildings followed by comparison of the obtained over-strength factors.

1.4 OBJECTIVES OF THE STUDY

This work attempts to evaluate effect of change of seismic zones on the design, detailing and performance of the building. The work includes comparison of base shear, percentage steel in columns and beams, and detailing of selected members. Moreover, it includes a performance comparison of the designed buildings on the basis of over-strength factors obtained from pushover analysis of the buildings.

1.5 SCOPE OF WORK

The following are scopes of the present work-

- All the modelling and analysis has been done for only RC structures.
- The beams and columns have been modelled as frame elements.
- Soil-structure interaction is not being taken into consideration.
- Foundation is modelled as a fixed support at the level of footing and the building design & material estimation exclude foundation.
- Infill walls have not been considered.

1.6 METHODOLOGY

The present study comprises of two stages-

i. Comparison of design and detailing requirement of an RC building for all the four earthquake zones(II,III,IV, and V),i.e, as in India. This will be done for 3 buildings with varying heights of five, seven and nine storey respectively. For every building, It will consist of the following steps-

- Modelling of the building with all the requisite parameters .
- Designing the building for all the four earthquake zones(as in India)

- Comparing of design and detailing for different earthquake zones.

ii. A comparison of performance of designed buildings for various seismic zones and detailing provisions using computer based “PUSH-OVER” analysis.

1.7 ORGANISATION OF THE THESIS

the organisation of forthcoming chapters is done as explained below-

i. Literature review on Seismic design of buildings, and use of Pushover analysis are provided in Chapter 2.
ii. The description of building, design and detailing comparison of aforementioned three RC buildings is explained in Chapter 3.
iii. Pushover analysis of the buildings and over-strength evaluation is explained in Chapter 4
iv. Chapter 5 consists of discussion of results and future scope of this study is dealt with.

2

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

2.1 General

In order to get a firsthand knowledge of the various seismic design and pushover analysis approaches, various research articles, design codes and relevant books were meticulously studied to understand the effect of seismic parameters on design & detailing of RC buildings. This helped in deciding requisite modeling methods and parameters to be used in seismic analysis and comparisons.

2.2 Structural modeling and design:-

Since a long time, researches are taking place regarding earthquake-resistant design of structures. Past earthquakes have been analysed by many and further research have been carried out to provide technical solutions that will bring down the loss of life and property during an earthquake to a minimum.

Kumar and Rao (2002) have carried out equivalent static analysis for a five (G+4) storied RC building in order to compare the variation of percentage steel when the building is designed for gravity loads as per IS 456:2000 and when designed for earthquake forces in all the seismic zones as per IS 1893:2002.Also,a detailed comparison of the vertical support reactions at supports, steel required for the footings and percentage steel for the columns and beams (done separately for interior and exterior members) was performed. Jain et al. (2008) has done the detailing comparison for some selected members of a six-storey building, considering it once as an OMRF and once as an SMRF. In it the comparison of detailing and amount of steel required for certain selected members of an RC buildings has been done mainly for seismic zones II and V. The detailings have been done considering three methods of design- considering a response reduction factor(R) of three (R=3) and detailing as per IS-456, considering R as five and detailing as per IS-456, and considering R as five and detailing as per IS-13920. Another aspect included in the present study is detailing comparison of the member, the methodology of which has been taken from the aforementioned work. Jain and Shah(2008) have carried out seismic analysis and design of a six storey building in which even after execution of design through software, at several critical sections checks have been performed manually in order to ensure pristineness of the design. A similar methodology has been adopted in this work as well wherein, at proposed critical sections, the longitudinal steel requirements and depth of section has been carefully checked with manual calculations .For this a meticulous study of Indian design code on RC structures IS 456,the annex to it on reinforcement detailing SP-16 as well as the Indian code on ductile detailing IS 13920 has been done. For the calculation of the lateral loads and seismic weight of building various loading estimates are specified in the code which have been used throughout this work. Samyog (2013) has done a study which involves cost comparison of RCC Columns in identical buildings based on number of Stories and Seismic Zones. This work presents that the detailing of columns of a building covering certain plinth area varies for a combination of storey and seismic zone. For a particular seismic zone, the relationship between the reinforcement of columns over a wide range of story is not necessarily linear. This was determined for 4, 6, 8 and 10 story buildings of identical nature for seismic zones III and V by using SAP2000 software.

2.3 Pushover Analysis

Another facet of this study involves performance evaluation of the designed buildings for various seismic zones and detailing provisions using computer based "PUSH-OVER" Analysis. The need of such an exercise has been well illustrated by Ghosh and Munshi (1998) in which it has been stated that the aim of the design codes is cardinally to minimize the life hazards and maintain a reasonable level of continued functionality of the essential components of building, thereby codal design provisions allow some extent of damage such as cracking of concrete and yielding of steel at certain locations at certain predisposed locations. In this work a 12-storey RC has been analysed for inelastic seismic performance under several earthquake ground motions.The method of pushover analysis proposed by Hasan *et al.* (2002), to use a plasticity-factor to precisely monitor the progressive plastification (stiffness degradation) of frame members under effect of increasing loads. The method has been illustrated by analyzing a three and a nine storey steel moment frame.

Athanassiadou (2008) analysed two ten-storeyed plane stepped frames and one ten-storeyed regular frame which were designed as per Euro code 8 (2004) for the high and medium ductility classes. In this work the Inter-storey drift ratios of the frames and plastic hinge formation in columns were monitored. In this work, the results of pushover analysis were presented using "uniform" load pattern as well as "modal" load pattern. Kadid and Boumrkik (2008), have advocated the Pushover Analysis as a viable tool to assess the actual seismic vulnerability of a code designed building. An incremental static analysis was carried out to develop a capacity curve for the building. Based on the capacity curve found from analysis, an estimate of the displacement which the design earthquake would probably produce on the building was determined. The extent of damage experienced by the structure considering the plastic yielding effects as well at the designated target displacement is taken into account for the analysis results.

2.4 Summary

An extensive review of previous research papers related to the present work and existing seismic design guidelines was done so that a proper methodology could be planned in order to do the design, comparisons and subsequent pushover analysis of the three buildings with varying storey heights as proposed in this present work.

3

SEISMIC DESIGN AND COMPARISONS

3.1 General

In order to fulfill the objectives, a building geometry with varying number of stories is chosen and designed as per different Indian seismic zones followed by a comparison of the design and detailing is presented in the Chapter.

3.2 Building Geometry and Design Considerations

The plan of the building frame considered the present study is shown in Fig 3.1. The building with the plan shown in this figure is considered for three different number of storeys five, seven and nine. Each of the building with their specific height are designed for all the seismic zones. The building designations with the seismic zone considered are shown in Fig 3.2. The designation, ‘G4ZII’ represents G+4 building designed for seismic zone II.

All the buildings are designed as per IS 1893 (2002) considering medium soil conditions.. The buildings in this study have column 3m , slab thickness 125mm and plinth level as 0.6m as observed from the study of typical existing residential buildings. Considering unit weight of concrete as 25Kn/m^3 and weight of floor finishes to be 1Kn/m^2,the slab dead load comes out to be 4.125kN/m^2. Taking the Live Load intensity as 3Kn/m^2 for floor slabs and 1.5kN/m^2 for roof slabs into account, and the earthquake loads as per IS 1893(part-1); all the thirteen load combinations have been considered for analysis (as in the code IS 1893(part-1). Buildings in zone II are designed considering them as OMRF and detailed according to IS:456, whereas Buildings in zone III,IV and V are designed considering them as SMRF and detailed according to IS:13920. The characteristic strength of concrete and steel are taken as 25MPa and 415MPa respectively

In order to study the design and detailing of the buildings selected, structural analysis is carried out for vertical and lateral loads. The comparison of design base shear, percentage of longitudinal steel in columns and beams are presented in the following sections. For all the three RC buildings, the following assumptions are made in this work-

- There is a common plan for all the buildings of dimensions 19 m x 10 m located on medium soil.
- The effect of finite size of joint width (e.g., rigid offsets at member ends) is not considered in the analysis.
- The floor diaphragms are assumed to be rigid.
- For analysis and design the Centre-line dimensions are considered.

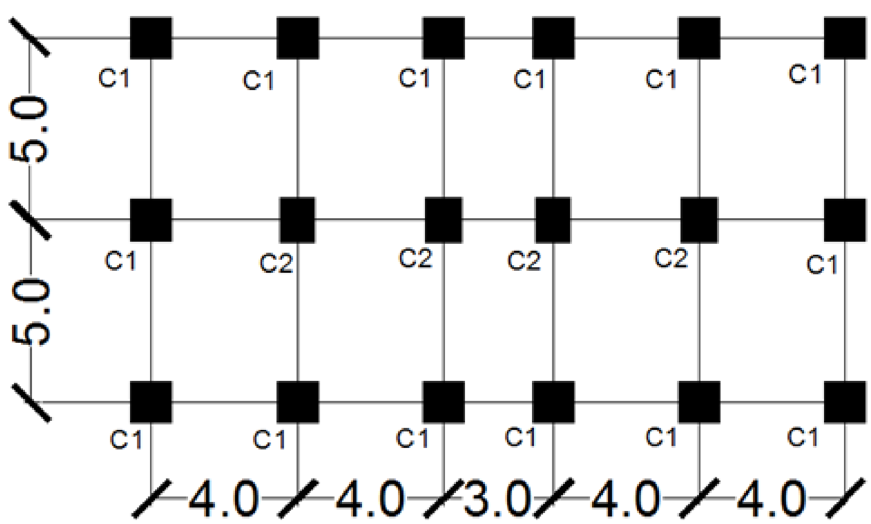


Fig 3.1: Plan of building.(all dimension in meters)

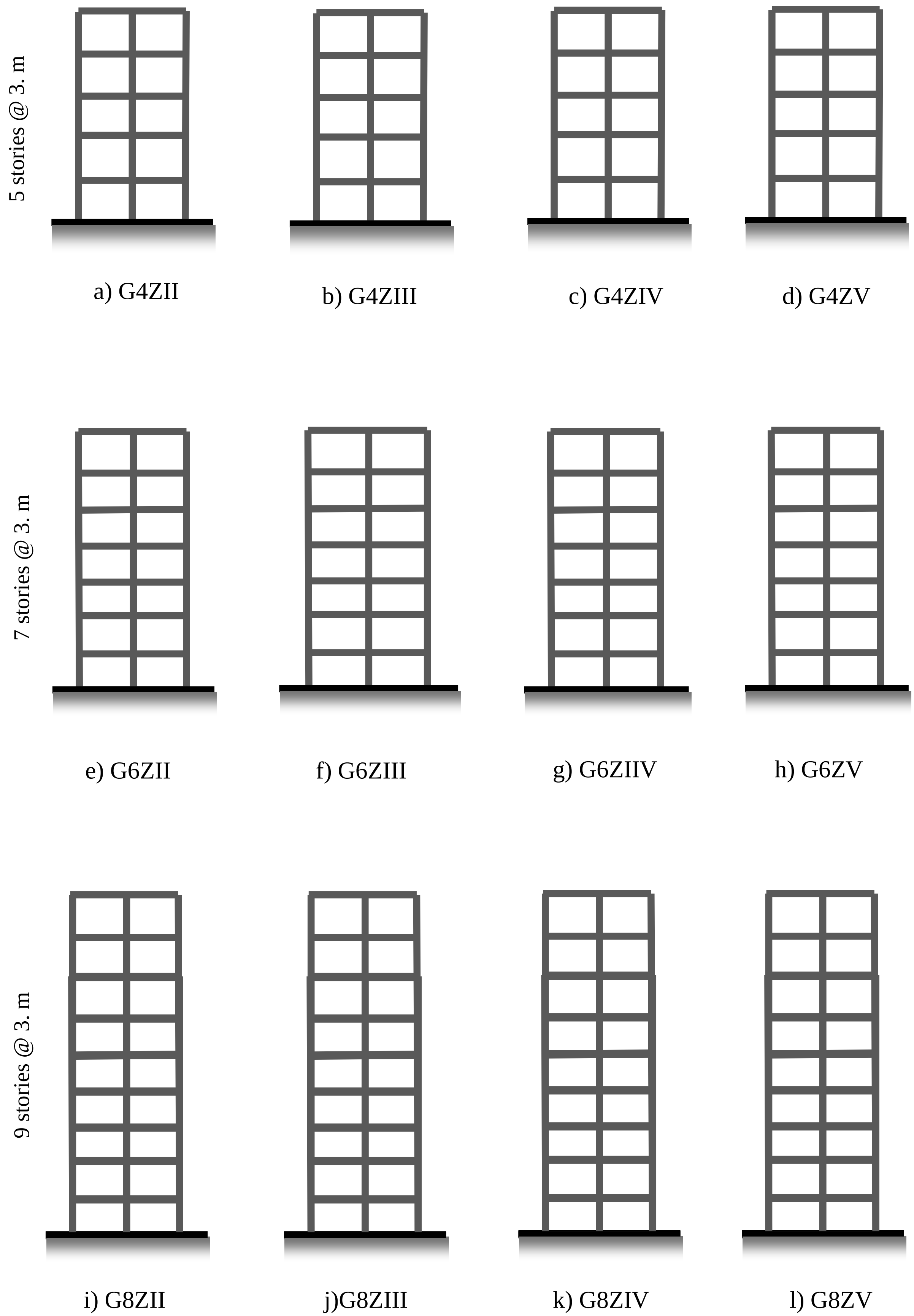


Fig 3.2 : Elevation of the selected frames

- **Schedule of member sizes:-**

Table 3.1 represents the beam and column sizes of the members for all the three buildings as chosen for design and subsequent detailing.B1 and B2 refer to interior and exterior beams, and similarly C1 and C2 refer to interior and exterior columns.

Table 3.1: member dimensions in “mm”

Type of building	B1	B2	C1	C2
G+4	350X300	450X300	400X400	500X400
G+6	400X300	600X300	450X450	600X450
G+8	500X300	600X450	500X500	600X500

3.3 COMPARISON OF DESIGN BASE SHEAR

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. Calculations of base shear depend on:

- soil conditions
- proximity to sources of seismic activity (such as geological faults)
- probability of significant seismic ground motion
- the level of ductility and over-strength associated with various structural configurations and the total weight of the structure
- the fundamental (natural) period of vibration of the structure.

The design base shear is calculated for all the different cases of varying storey heights and seismic zones as per equivalent static method (IS 1893, 2002) and is shown in table 3.2.From the design base shear results, it can be clearly observed that there is a significant increase in base shear as we move from zone II to zone V, indicating the increase in severity of earthquakes occurring in these regions. Moreover, from the Fig 3.3, it is evident that magnitude of design Base Shear increases with the increase in height of a building.

Table 3.2: Design Base shear values for the designed frames

Frame identity	Design Base Shear(kN)
G4ZII	858
G4ZIII	921
G4ZIV	1125
G4ZV	1340
G6ZII	1190
G6ZIII	1272
G6ZIV	1723
G6ZV	2170
G8ZII	1851
G8ZIII	1920
G8ZIV	2362
G8ZV	2814

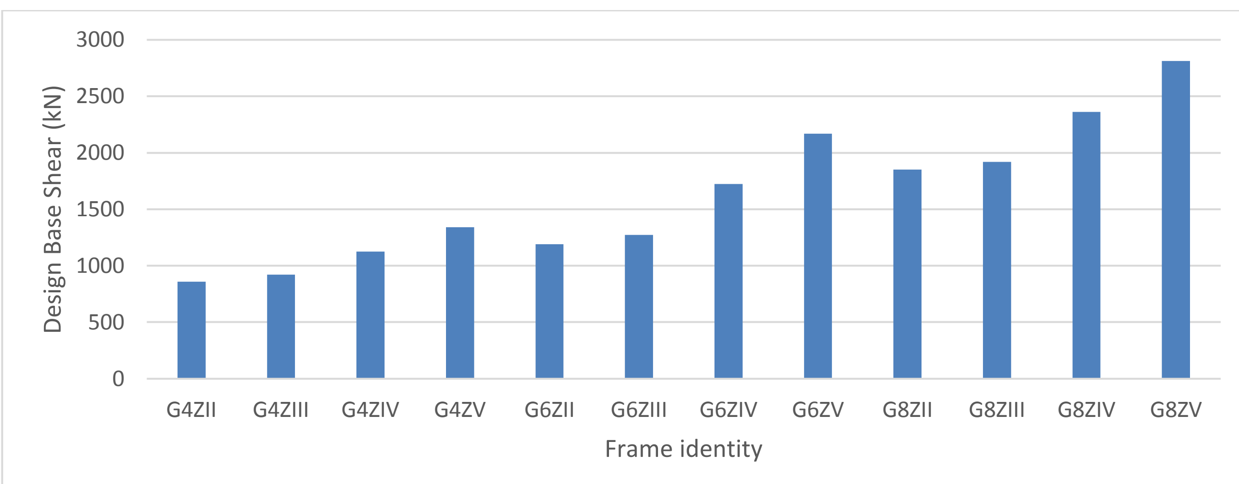


Figure 3.3 : Comparison of Design Base shear values

3.4 COMPARISON OF PERCENTAGE OF LONGITUDINAL STEEL IN COLUMNS

The percentage steel in both exterior as well as interior columns was calculated. The variation of percentage of longitudinal rebars of the column in different seismic zones is depicted in the in Table 3.3. The variation of percentage of steel in exterior columns is from 0.9% to 3% and interior columns varying from 1.1% to 3.1% as one moves from zone II to zone V. In addition to this. It is evident that as we move to higher seismic zone, the steel reinforcement requirements increase.

Table 3.3: Comparison of percentage of longitudinal steel in columns

Frame identity	percentage of longitudinal steel in columns	
	Exterior columns	Interior columns
G4ZII	.91	1.2
G4ZIII	1.3	1.8
G4ZIV	1.9	2.3
G4ZV	2.4	3.0
G6ZII	.97	1.32
G6ZIII	1.57	1.91

G6ZIV	2.1	2.5
G6ZV	2.7	3.1
G8ZII	1.13	1.39
G8ZIII	1.51	1.97
G8ZIV	2.2	2.6
G8ZV	2.7	2.89

3.5 COMPARISON OF PERCENTAGE LONGITUDINAL STEEL IN BEAMS

A beam is a member that is capable of withstanding loads primarily by resisting flexure. The bending force induced into the material of the beam as a result of the external loads, own weight and external reactions to these loads is called as bending moment. In RCC, Beams are characterized by their profile (shape of cross-section), their length, and the amount of steel provided. The percentage longitudnal steel in both exterior as well as interior beams was calculated both at supports as well as midspan and has been tabulated below table 3.4 as shown. The variation of percentage of steel at support sections in external beams is approximately 0.54% to 1.23% and in internal beams is 0.78% to 1.4%. In the external and internal beams, the percentage of bottom midspan reinforcement underwent comparatively lesser increment to about 15-20% for different earthquake zones. It is evident that as we move to higher seismic zone, the steel reinforcement requirements increase.

Table 3.4: Comparison of percentage of longitudinal steel in beams

Frame identity	percentage of longitudinal steel in beams			
	Exterior beams		Interior beams	
	At supports	At midspan	At supports	At midspan
G4ZII	.66	.38	.81	.41
G4ZIII	.76	.42	.96	.57
G4ZIV	.87	.56	1.2	.65
G4ZV	1.2	.65	1.41	.76
G6ZII	.77	.48	.89	.51
G6ZIII	.89	.52	1.07	.67
G6ZIV	.98	.63	1.23	.78
G6ZV	1.3	.71	1.51	.86
G8ZII	.8	.58	.93	.61

G8ZIII	.93	.62	1.05	.67
G8ZIV	1.02	1.02	1.27	.75
G8ZV	1.4	1.4	1.57	.81

3.6 COMPARISON OF REINFORCEMENT DETAILING

In order to get a more fair idea of the differences in steel reinforcement and detailing requirements of individual members, we chose an interior beam and an interior column of the G+4 and G+8 building. Buildings in zone II are designed considering them as OMRF and detailed according to IS:456,whereas Buildings in zone III,IV and V are designed considering them as SMRF and detailed according to IS:13920.

3.6.1 Detailing of selected beam and column for G+4 building

For the building in zone II, IS 456 has been used to make detailing, while for zone V,IS 13920 has been utilised for the detailing purposes. From the design results, the following detailing sketches have been drawn. The principal objectives of the ductile design of reinforced concrete members are to ensure both strength and ductility for the designed structures or members. Strength of members can be assured by proper design of the sections following limit state method even. However, for ensuring ductility in higher seismic zones, specific recommendations are to be followed as given in IS 13920:1993 regarding the materials, dimensions, minimum and maximum percentages of reinforcement. Further, detailing of reinforcement plays an important role as well .Fig 3.6 and Fig 3.5 represent the detailing comparison for beams in zone II and V. It can be seen that in zone V, the transverse steel is more closer, accounting for a higher ductility of the structure as per codal provisions. Fig 3.7 represent the detailing comparison for columns in zone II and V. It can be seen that in zone V, the transverse steel (nominal links) is more closer, accounting for a higher ductility of the structure as per codal provisions. Also there is a special provision for confining links, which account for increased resistance especially at the beam-column joints.

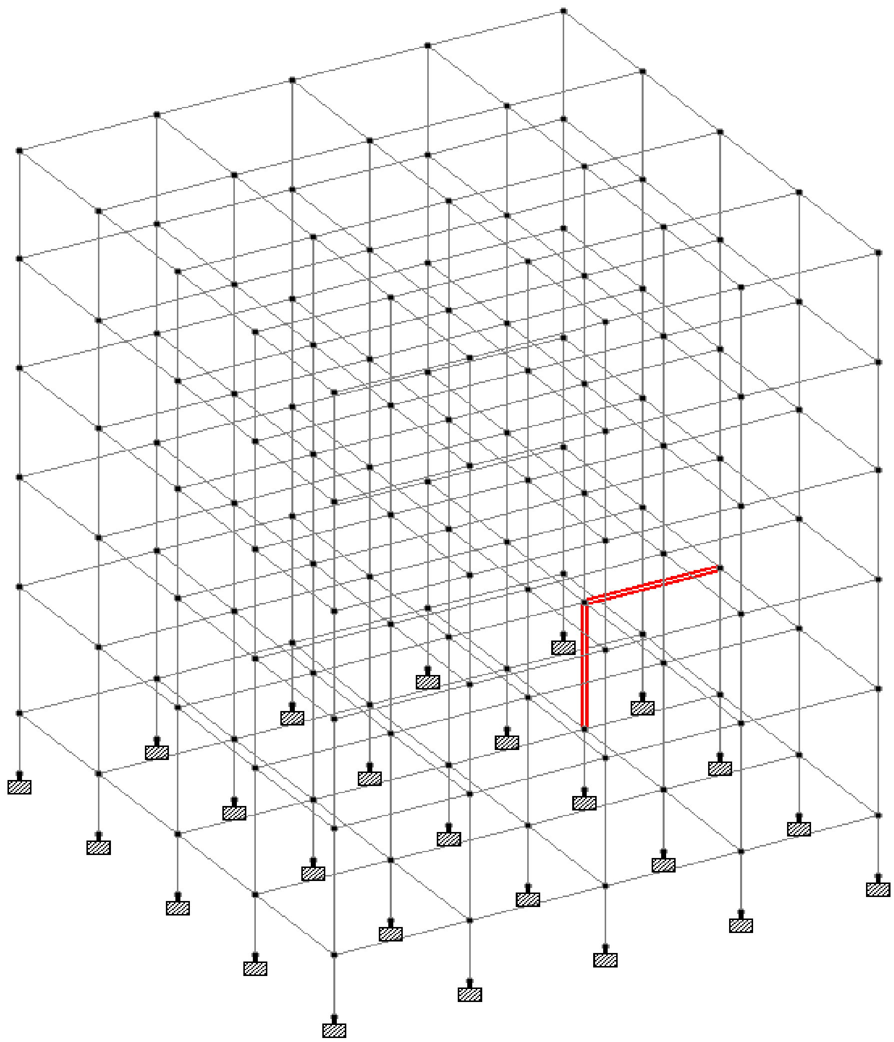


Fig 3.4 : 3-d view of the G+4 building model, highlighted members indicate the ones which have been considered for detailing

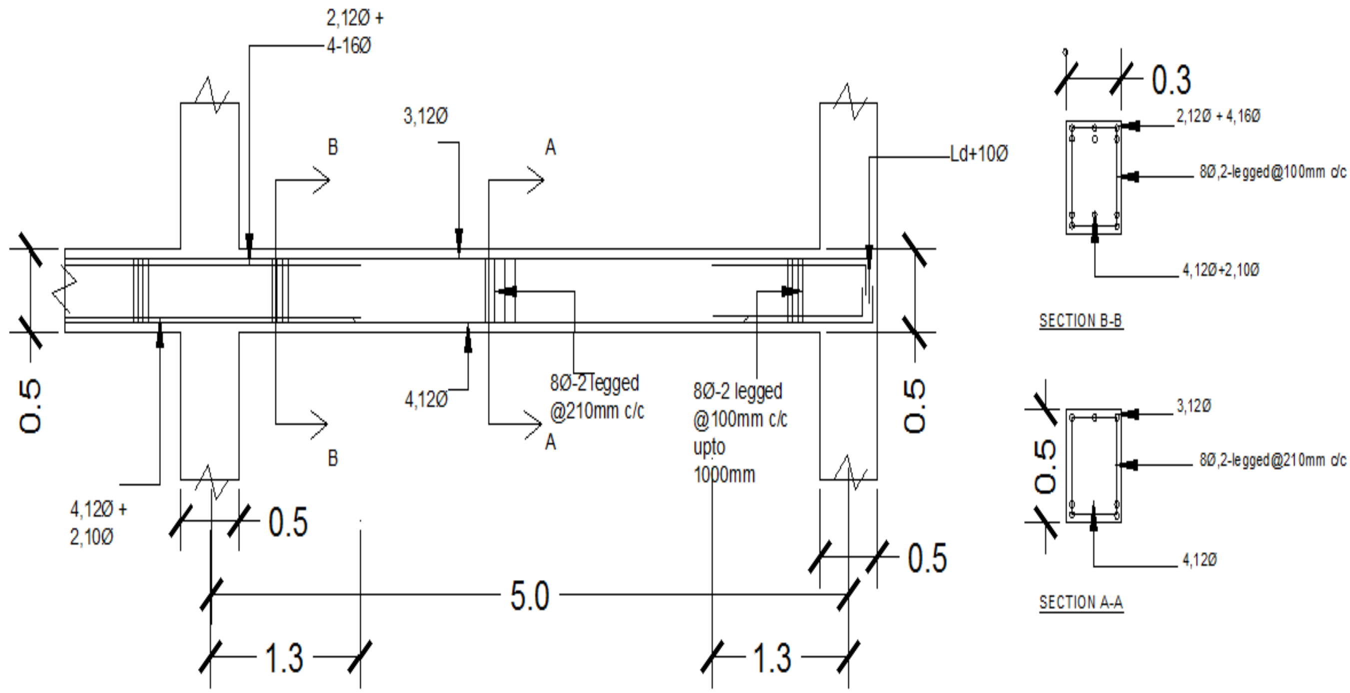


Fig 3.5 : reinforcement detailing for an interior beam of G4ZV

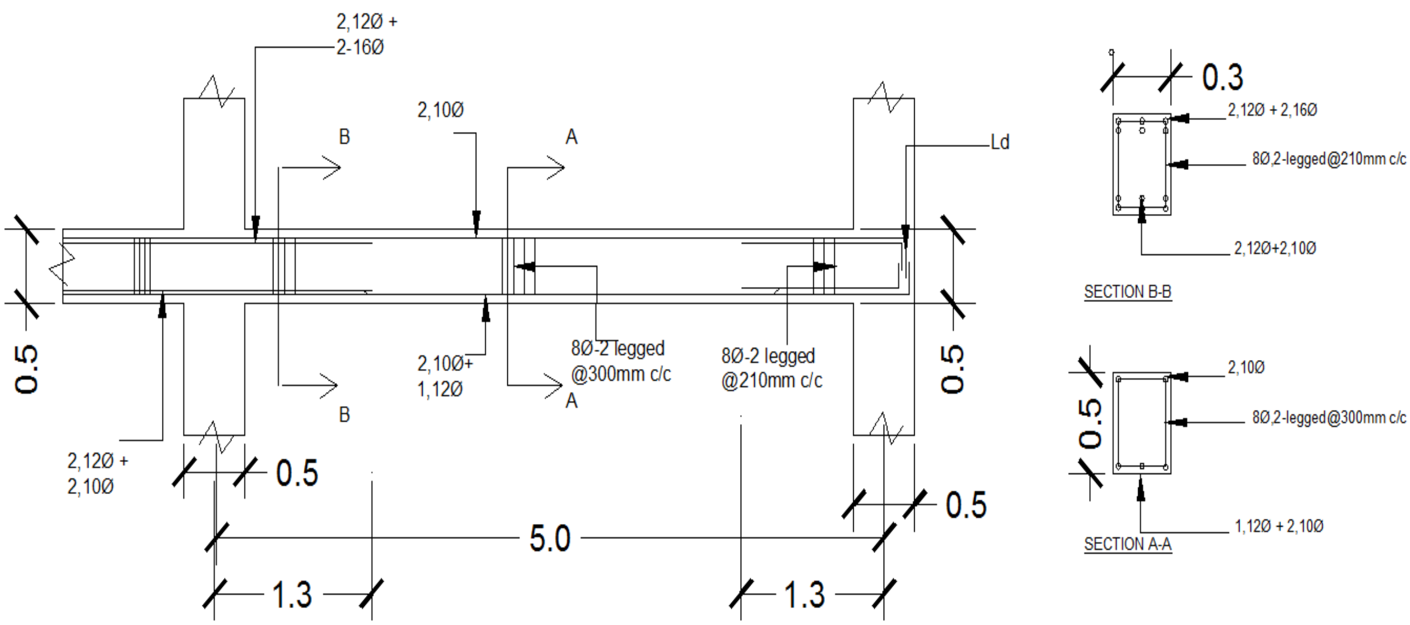


Fig 3.6 : reinforcement detailing for an interior beam of G4ZII

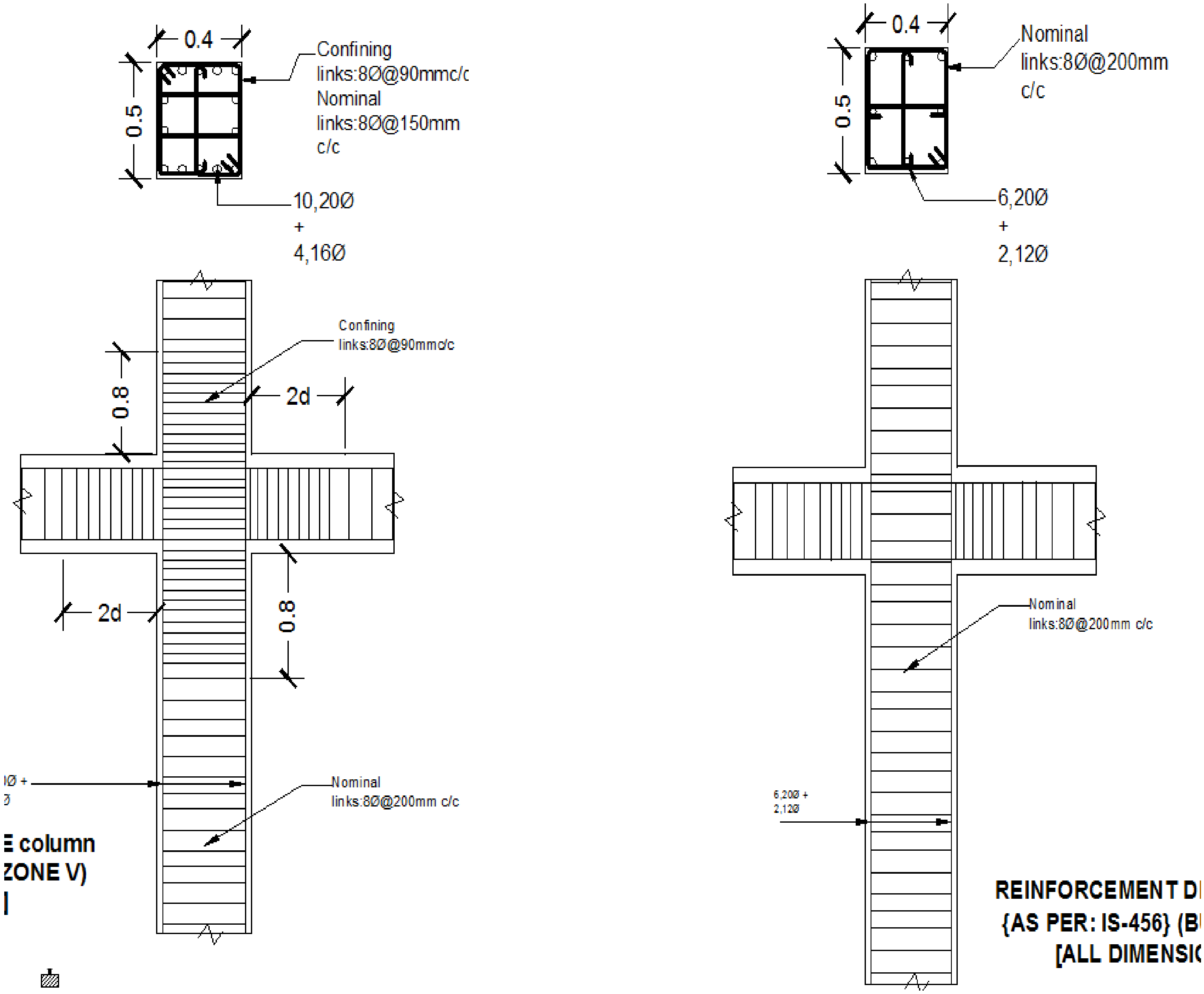


Fig 3.7 : reinforcement detailing for an interior column of the building seismic zone V and zone II respectively

3.6.2 Detailing of selected beam and column for G+8 building

For the building in zone II, IS 456 has been used to make detailing, while for zone V,IS 13920 has been utilised for the detailing purposes. From the design results, the following detailing sketches have been drawn. Fig 3.8 and Fig 3.9 represent the detailing comparison for beams in zone II and V. It can be seen that in zone V, the transverse steel is more closer , accounting for a higher ductility of the structure as per codal provisions. Fig 3.10 represent the detailing comparison for columns in zone II and V. It can be seen that in zone V, the transverse steel (nominal links) is more closer, accounting for a higher ductility of the structure as per codal provisions. Also there is a special provision for confining links, which account for increased resistance especially at the beam-column joints.

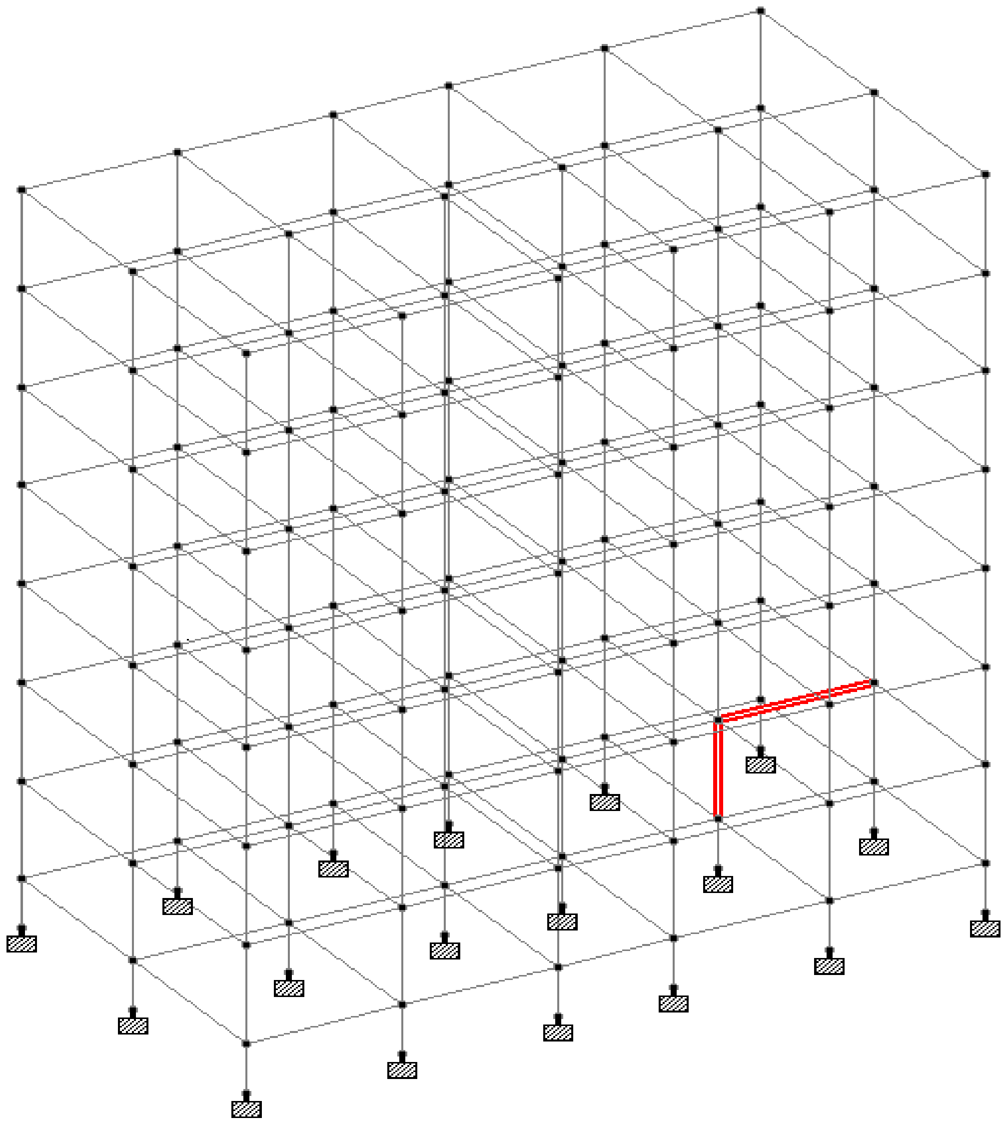


Fig 3.8: 3-d view of the building model, highlighted members indicate the ones which have been considered for detailing.

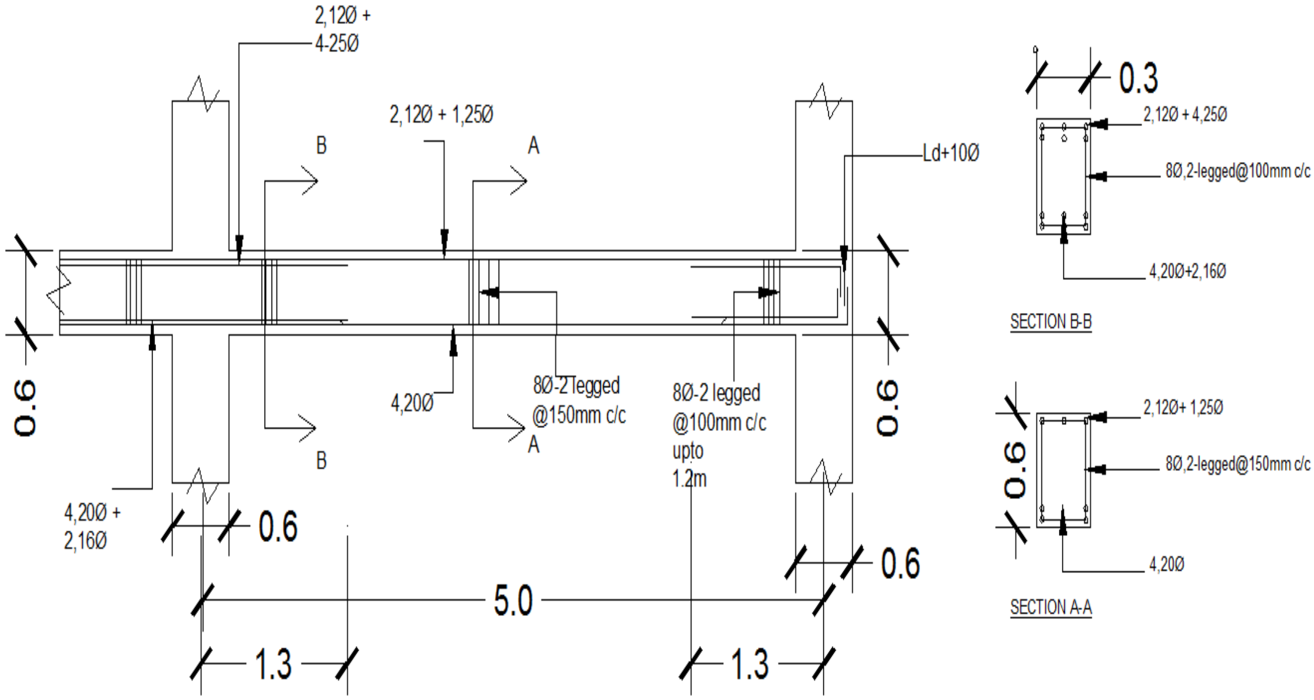


Fig 3.9 :_reinforcement detailing for an interior beam of G8ZV

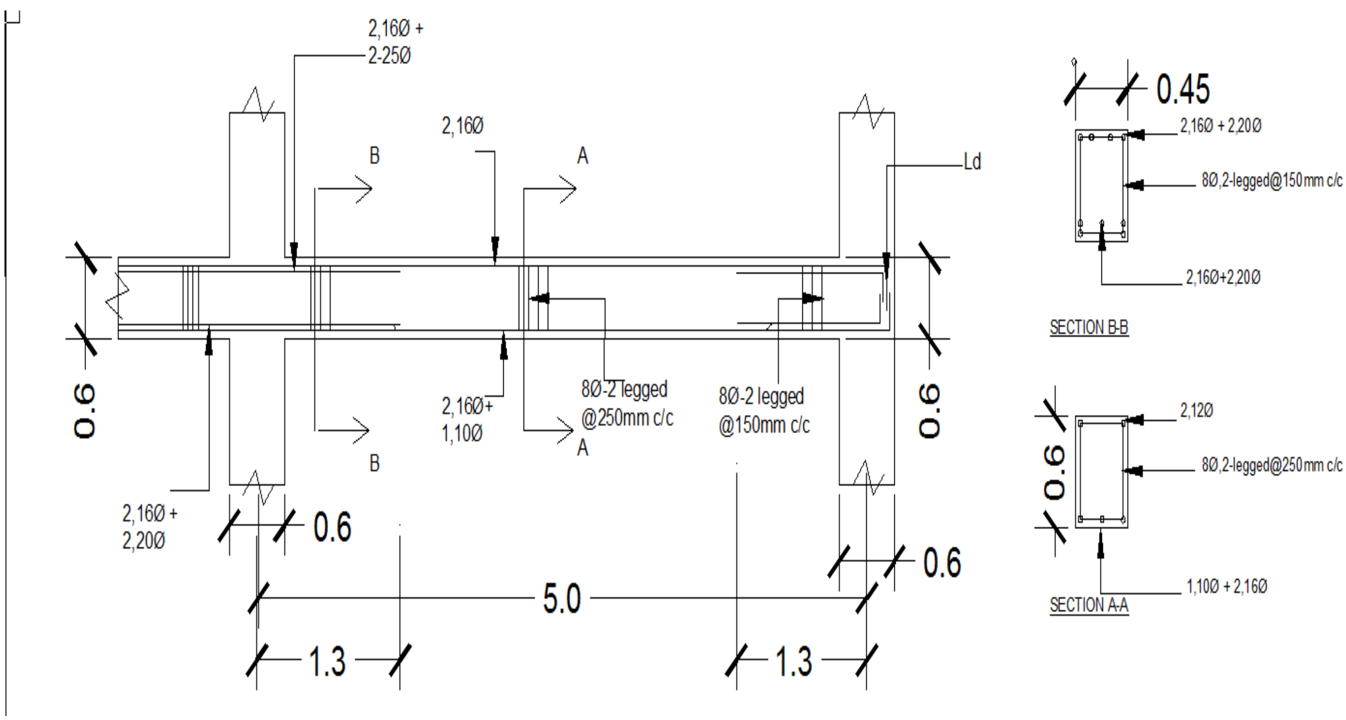


Fig 3.10 : reinforcement detailing for an interior beam of G8ZII

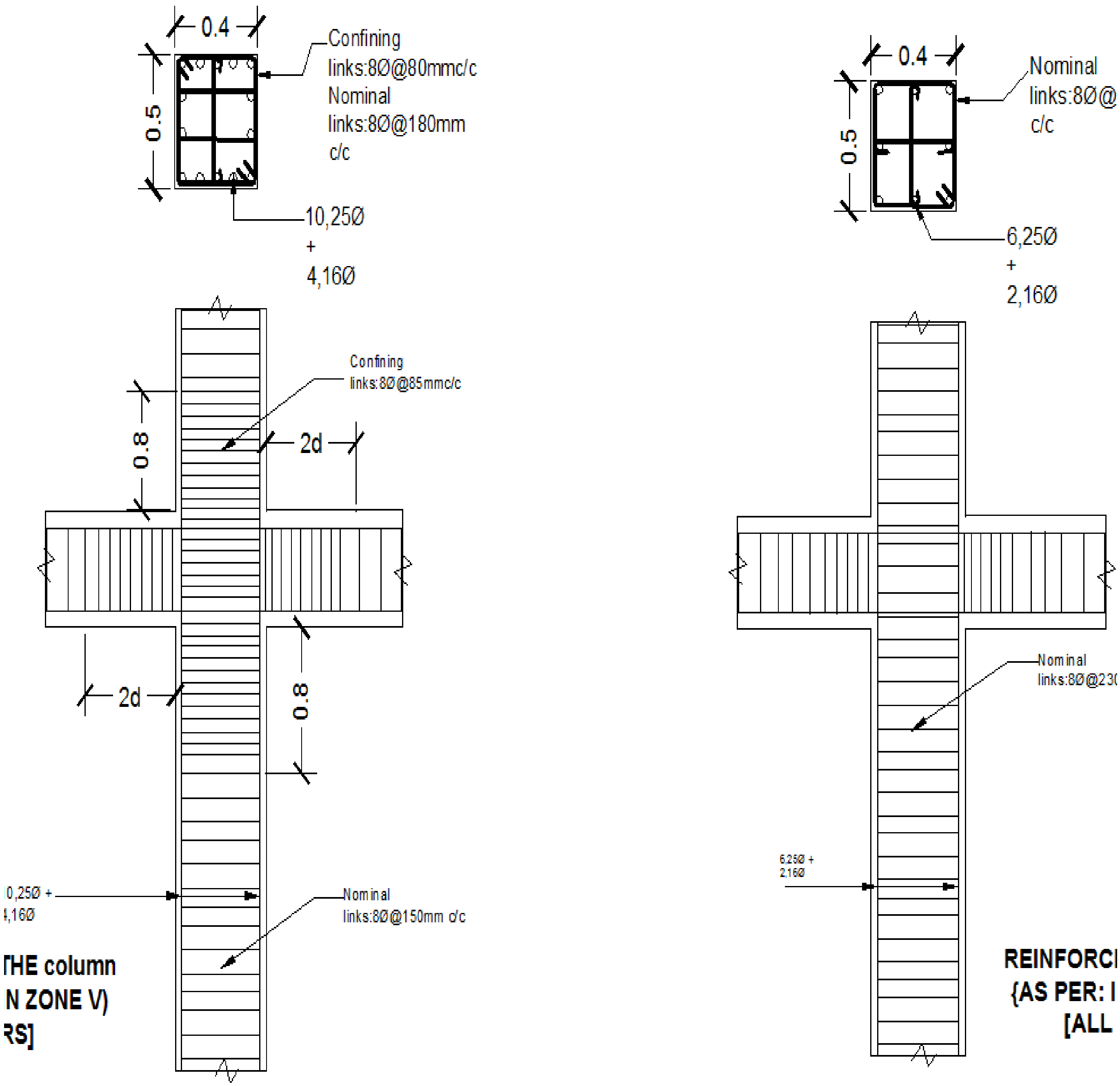


Fig 3.11 : steel reinforcement detailing for an interior column of the building seismic zoneV and zone II

3.7 SUMMARY

All the aforementioned buildings were designed appropriately as per their respective zones and then detailed accordingly. The results were carefully evaluated. It can be clearly seen that there is significant increase in base shear as we move from zone II to zone V, indicating the increase in severity of earthquakes occurring in these regions. In addition to this, from the base shear variation, it is evident that magnitude of Base Shear increases with the increase in height of a building. It can be concluded that as far as steel requirement in columns is concerned, it almost increased to 43%(for exterior as well as interior columns) on average when we move from zone II to Zone V. The detailings were meticulously drawn so as to give a clear picture of the differences in codal provisions with seismic zones. In the next chapter, pushover analysis of all these buildings has been done to determine their over-strength factors.

4

PUSHOVER ANALYSIS

CHAPTER 4

PUSHOVER ANALYSIS

4.1 GENERAL

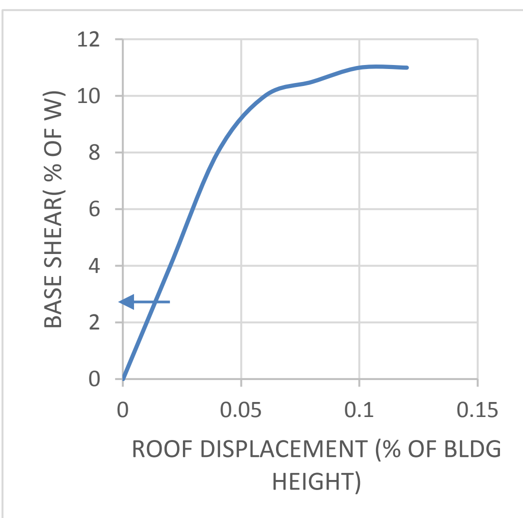
Pushover analysis is a non-linear, structural analysis procedure, which is widely used to explain structural behavior due to various types of loads resulting from an earthquake. In this study, over-strength factor obtained from the pushover curve of the buildings was used as the parameter to assess this amount of reserve strength when the buildings have been designed as per the Indian seismic codal provisions.

4.2 MODELLING FOR PUSHOVER ANALYSIS

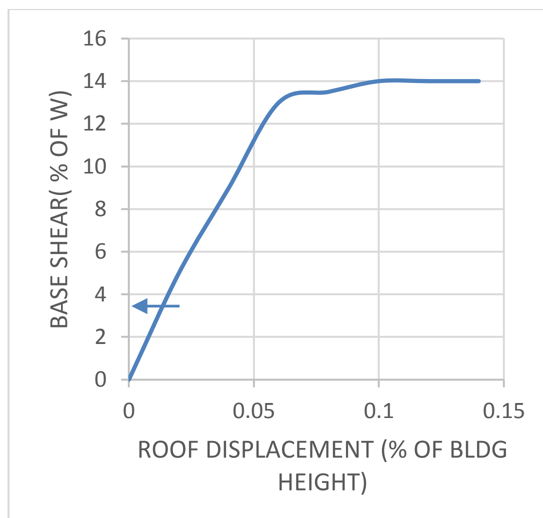
In order to perform the pushover analysis, the buildings were modelled with all the appropriate previously determined member sizes and reinforcements. Then non-linear hinges were defined with appropriate non-linear properties (force-displacement or moment-rotation diagrams) in a structure model. Thereafter, hinges were assigned to all the beams and columns. This was followed by assigning each floor slab a rigid diaphragm. A set of lateral forces was defined subsequently, and the nature of force was taken to be non-linear and displacement controlled. Finally, all other parameters of the non-linear analysis were defined. After completion of the analysis, the Over-strength factor was determined from the respective Pushover curves.

4.3 PUSHOVER CURVES FOR ALL THE DESIGNED BUILDINGS

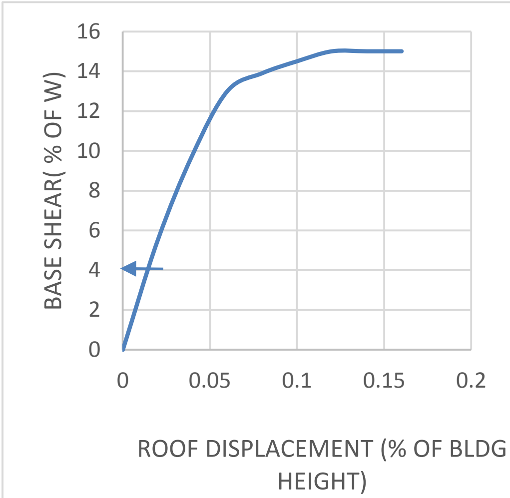
The pushover curves obtained have been made dimension-free by dividing the roof displacement with height of the building (abscissa) and base shear with the building's seismic weight (ordinate).Fig 4.1 depicts the non-dimensional pushover curves obtained for all the three buildings in the various seismic zones (the arrowheads indicate the amount of Base shear for which the building has been designed).Pushover curves have been shown below for the all the RCC framed buildings considered. The first set of curves is for G+4 building, followed by G+6 and G+8 building respectively .It is found that after zone III there is a significant increase in the base shear which can be seen from the pushover curves for zone IV and zone V respectively, indicating the increase in severity of earthquakes occurring in these regions.



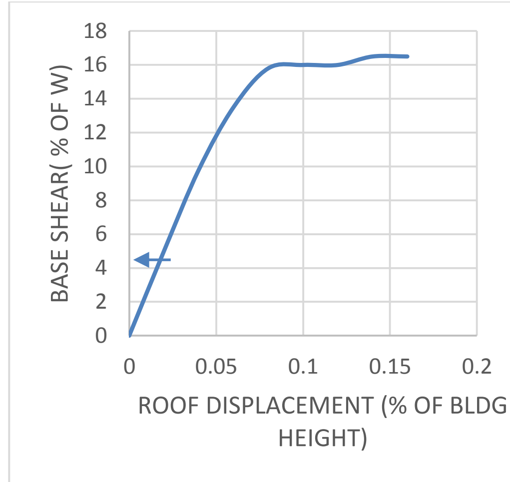
a) Pushover curve for G4ZII



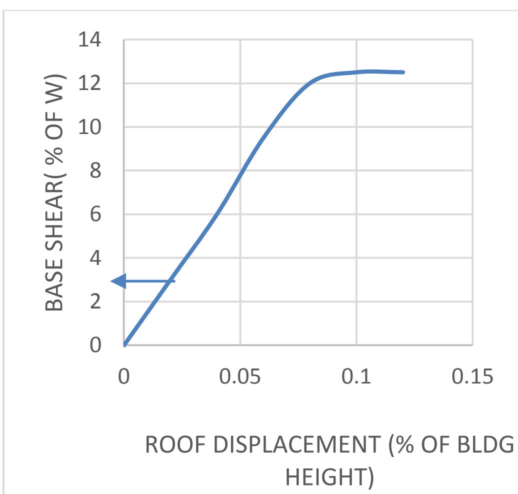
b) Pushover curve for G4ZIII



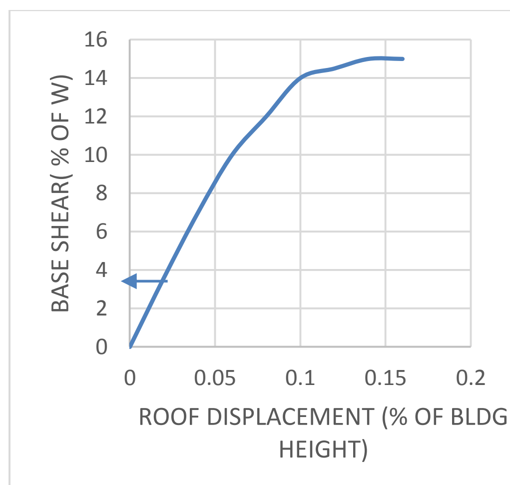
c) Pushover curve for G4ZIV



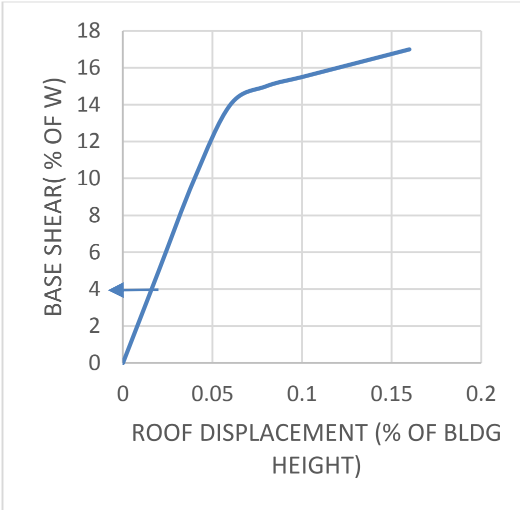
d) Pushover curve for G4ZV



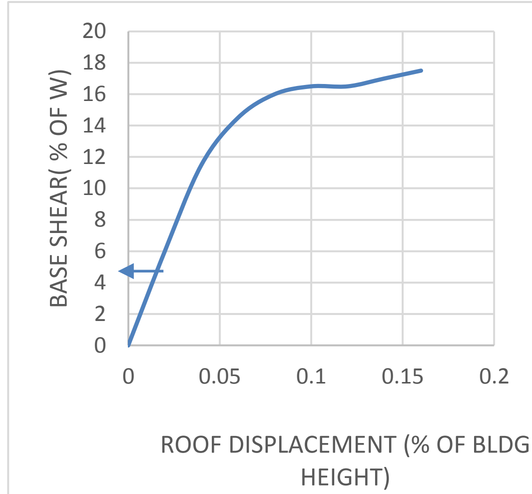
e) Pushover curve for G6ZII



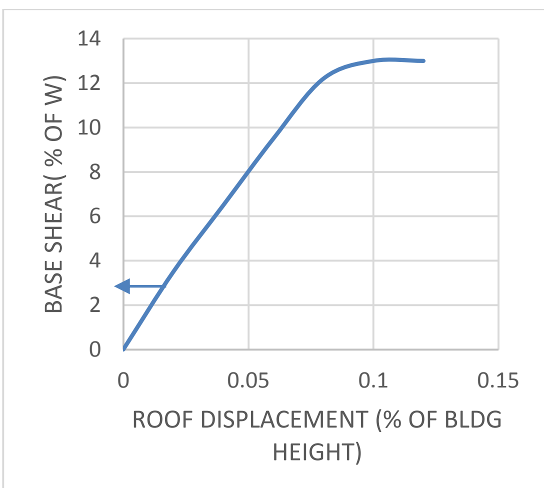
f) Pushover curve for G6ZIII



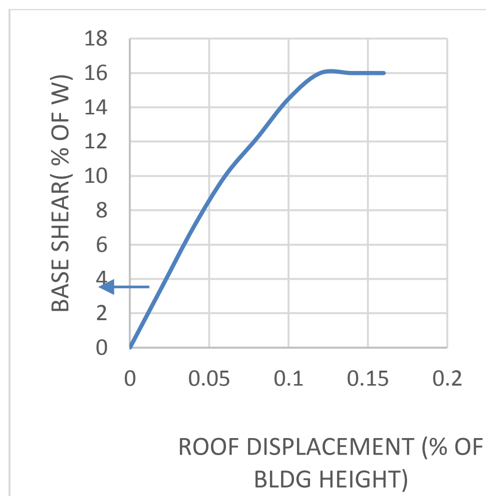
g) Pushover curve for G6ZIV



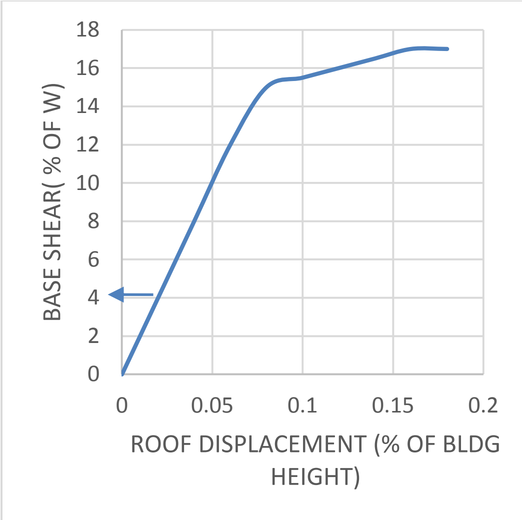
h) Pushover curve for G6ZV



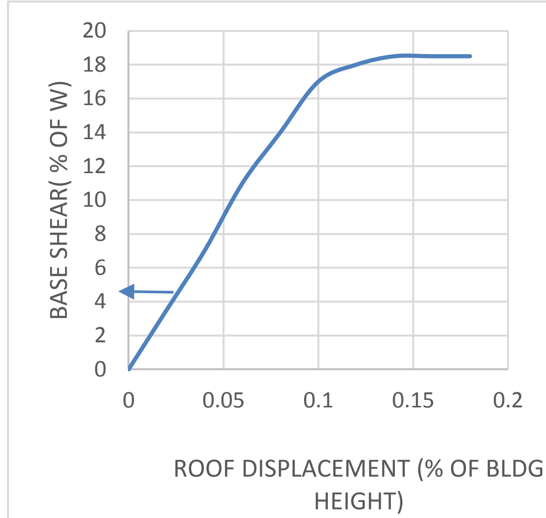
i) Pushover curve for G8ZII



j) Pushover curve for G8ZIII



k) Pushover curve for G8ZIV



l) Pushover curve for G8ZV

Fig 4.1: Non-dimensional Pushover curves

4.4 Over-Strength evaluation of Frame G4ZIV

From the pushover curve obtained for the building, we can see that the building has been designed to resist a base shear of 1125.1 kN, but actually it is capable of taking upto about 3500kN.

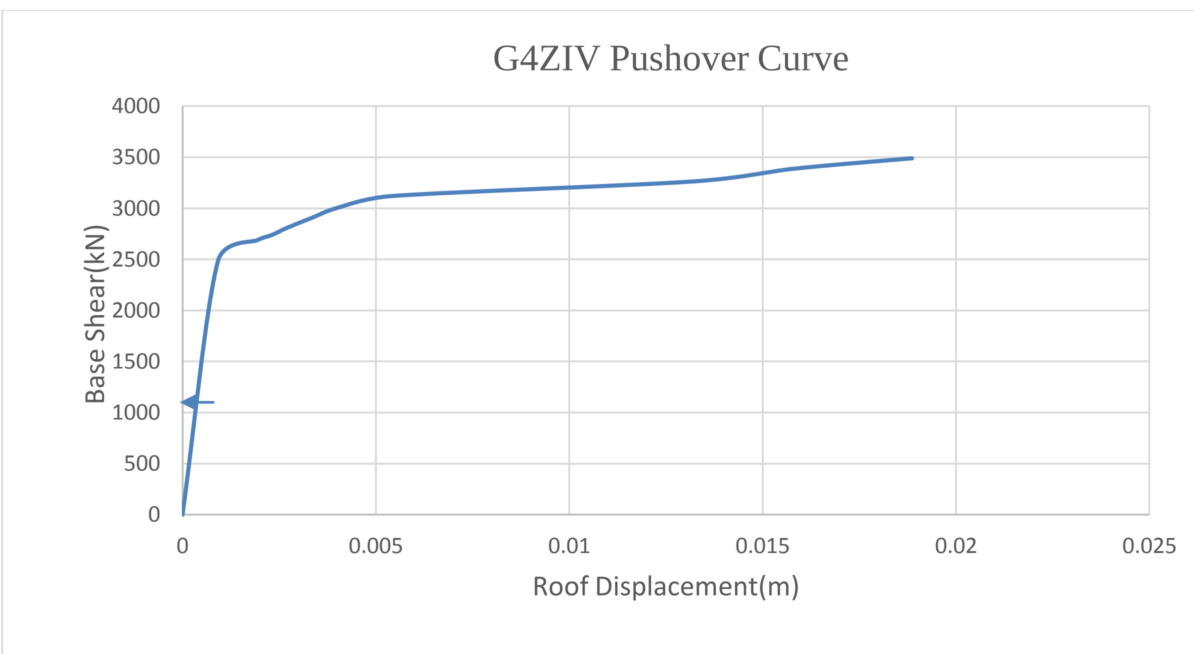


Fig 4.2: Pushover curve for G+4 Building in Zone-iv

Thus, the over-strength factor is equal to

Over-strength Factor = 3500/1125.2= 3.21

Thus, the G+4 building when designed according to the Indian Codal provisions for seismic zone IV, has an actual ability to take 3.21 times more force to which it has been designed for.

4.5 COMPARISON OF OVER-STRENGTH FACTOR

From the obtained pushover curves, over-strength factors were calculated for the buildings table 4.1. From the analysis of over-strength factor in Fig 4.3 ,we find that it tends to decrease with increase in height of the building. The over-strength factors for all the buildings for the various seismic zones can be listed as follows-

Table 4.1: Over-strength factor comparison

Building	Over-Strength Factor			
	ZONE II	ZONE III	ZONE IV	ZONE V
G+4	2.3	2.73	3.21	3.77
G+6	2.16	2.51	3.1	3.41
G+8	2.03	2.28	2.92	3.23

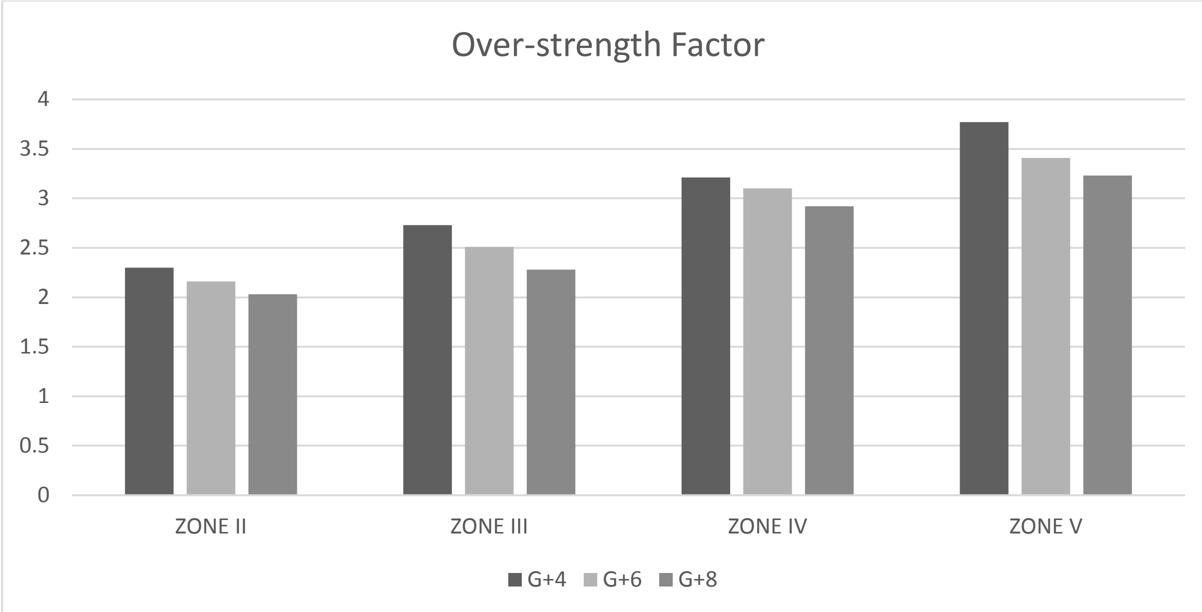


Fig 4.3 : Over-strength factor comparison

4.6 SUMMARY

Over-strength factor obtained from the pushover curve of the buildings was used as the parameter to assess this amount of reserve strength when the buildings have been designed as per the Indian seismic codal provisions. A total of twelve pushover curves were made, four for each building corresponding to the four Indian seismic zones. From the analysis of over-strength factor, we find that it tends to decrease with increase in height of the building. There is significant increase in base shear as we move from zone II to zone V, indicating the increase in severity of earthquakes occurring in these regions. Moreover, from the Base Shear curves, it is evident that magnitude of Base Shear increases with the increase in height of a building.

5

SUMMARY AND CONCLUSIONS

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

Analysis of several past numerous seismic tremors have demonstrated that building structures have the capacity to manage without any harm the seismic constraints bigger than those they were intended for during design. For the seismic design of structures most codes, indeed, indicate just a solitary configuration tremor which the building and its segments are required to maintain without breakdown. The building is expected to experience some basic and nonstructural damage amid the configuration earthquake. Furthermore, it is expected that the building outlined in this way will consequently meet the objective of no harm in a moderate intensity earthquake. Along these lines, a large number of the seismic design codes have a tendency of downsizing the design forces to record for reserve strength parameter which is crucial and simplifies the analysis as well .Pushover Analysis can help demonstrate how progressive failure in buildings really occurs, and identify the mode of final failure. In this study, over-strength factor obtained from the pushover curve of the buildings was used as the parameter to assess this amount of reserve strength when the buildings have been designed as per the Indian seismic codal provisions. In addition to it, several other entities such as percentage steel and base shear were also compared to get an idea on the variation of these quantities with varying building heights and seismic zones. The conclusions obtained from the study and the future scopes of this research are quoted in this chapter.

5.2 CONCLUSIONS

The following are the major conclusions that can be made based on present work carried upon the three RC buildings with different heights designed for earthquake forces in all the seismic zones-

1. There is significant increase in base shear as we move from zone II to zone V, indicating the increase in severity of earthquakes occurring in these regions.
2. Moreover, from the Base Shear curves, it is evident that magnitude of Base Shear increases with the increase in height of a building.
3. As far as steel requirement in columns is concerned, it almost increased to 43%(for exterior as well as interior columns) on average when we move from zone II to Zone V.
4. The variation of percentage of longitudinal steel at support sections in external beams is approximately 0.54% to 1.23% and in internal beams is 0.78% to 1.4%.
5. In the external and internal beams, the percentage of bottom middle reinforcement underwent comparatively lesser increment to about 15-20% for different earthquake zones.
6. There has been a steady rise in overall steel requirements in the building to about 35%,as we move from zone III to zone V.
7. From the analysis of over-strength factor, we find that it tends to decrease with increase in height of the building.

5.3 SCOPE OF FUTURE WORK

On the basis of the present work done, the scope for future study is identified on the following aspects-

- In the present study, seismic design of buildings is carried out using Equivalent Static analysis. Similar studies may be taken up with other methods such Response-spectrum Analysis, Time-History Analysis.
- In this work, only the Indian Seismic design codes have been taken into account, the work can be further extended by incorporation of British, American and other design codes as well.
- The present study considers only the over-strength factor obtained from the Pushover Analysis output. Several other parameters such as- Capacity spectrum, hinge-backbone results, etc., can also be augmented to it.
- Efforts may be made to take the soil-structure interaction into account as well.
- The present study is carried out on RC buildings. Similar studies may be taken up with Steel structures as well.
- Efforts may be made to study the pushover analysis using different software tools or some other procedures to validate the results.

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